direct vision. It is probable, therefore, from the similarity of the results at the two angles, that it continues to do so in the more peripheral parts of the retina, although it has lost its other function, of color-sensation.

The results at 70° confirm in a general way the measurements of von Kries. His results are given in Table III., with the column for 70° from the flicker experiments, both also reduced to the value unity in the yellow for purposes of comparison.

TABLE III.

	VON KRIES.		WHITMAN.	
	Original Values.	Reduced.	Original Values.	Reduced.
R.	1.35	.199	.079	.130
O.	4.03	.594	.222	.337
Y.	6.78	1.000	.660	1.000
Y.G.	.....	.....	.478	.724
G.	4.92	.726	.391	.592
B.G.	3.87	.571	.....	.....
G.B.	.....	.....	.344	.521
B.	.....	.....	.193	.292
V.	.86	.127	.....	.....

The two sets of measurements, though differing considerably in detail, show a progression in brightness of a similar character, especially as to the position of the maximum. An inspection of the table makes it evident that differences in the results might possibly be explained by the assumption of slight differences in the pigments used by the two observers; but it is perhaps more probable that the difference is a real one, caused by the fact that my observations were made in a darkened room, and, therefore, with an eye more 'adapted for darkness' than that of von Kries, who worked in a well-lighted place.

While it appears evident, as von Kries holds, that the color-perceiving apparatus is of importance in determining the brightness of any color peripherally seen, it is plain that—in the language of his theory—the apparatus for twilight vision plays a more important part than in the central portions of the retina. For the diminution of the reds and increase of the blues in brightness are characteristic only of faint illumination by direct vision—illumination fainter than the lowest at which the flicker method can be advantageously used (*Physical Review, loc. cit.*, p. 247), whereas they are shown by these experiments to exist in the outer regions of the retina under conditions of considerable brightness.

It may be said, in conclusion, that the brightness-sensation of the retinal periphery, so far as it differs from that of the central portions, differs from it in the same direction, though not so greatly, as in the other two types of complete color-blindness.

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*AN EXTENSION OF HELMHOLTZ'S THEORY OF THE HEAT OF THE SUN.**

ON the occasion of the Kant Commemoration at Königsberg, February 7, 1854, Helmholtz delivered an address on the 'Interaction of Natural Forces,' in which he laid the foundation of the modern theory of the sun's heat. The whole address, with the principal formulæ by which the numerical results were obtained, was translated into English and published in the *Philosophical Magazine* for 1856. In this paper the author discusses the conservation of energy, which he had been so instrumental in establishing upon a sound mathematical basis; and ascribes the maintenance of the sun's heat to the potential energy given up by the particles in descending towards the center of his globe. On the hypothesis that the solar sphere is of homogeneous density he subjects the problem to computation, and finds that the heat developed by a very small shrinkage of the mass will be sufficient to

* Read before the Philosophical Society of Washington, May 13, 1899.

account for the observed radiation. His principal conclusions may be summarized as follows:

1. That a shrinkage in the radius of 35 meters per year will generate sufficient heat to sustain the annual output of radiant energy.

2. That on this basis the radius of the sun would not shrink more than $\frac{1}{10000}$ part in 2,000 years, and this shrinkage could not be detected by any measurements which have been made within historical time. For the mean value of the sun's radius is about 961 seconds of arc, and is still uncertain by about one-half second; $\frac{1}{10000}$ of this radius is thus but one-fifth of the outstanding uncertainty in the sun's semi-diameter, in spite of all the labor which has been spent in finding its exact value by refined measurement. As the diameters noted by the ancients are much less accurate than those which can be inferred from the recorded duration of ancient eclipses in conjunction with the theory of the moon, we can only say that there is no evidence that the radius has diminished since the earliest ages. Even with the finest measurements now available, it would take ten thousand years for the shrinkage to become clearly sensible. There is, therefore, little hope that the shrinkage of the sun can ever be observed, yet from known mechanical laws we may confidently compute its amount, with even greater accuracy than we could hope to obtain from direct measurement.

3. That all the energy generated in the mass of the sun by the falling together of its particles would suffice to raise an aqueous globe of the same mass to a temperature of over 27 million degrees Centigrade. Pouillet estimated from experiments on solar radiation that the heat annually lost by the sun would raise the temperature of such a globe 1.25° C. On this basis the observed radiation of the sun could not have gone on uniformly in the past for more than about 22 millions of years. As more modern estimates increase the observed radiation appreciably, when full account is taken of atmospheric absorption, we shall adopt 18 million years as the past duration of the sun, on the theory of uniform radiation and homogeneous density assumed by Helmholtz.

4. Helmholtz further shows that all the energy given up by the condensation of the several planets amounts to but little more than $\frac{1}{100000}$ part of that developed by the condensation of the sun, and that the energy of the motion of the planets amounts to only $\frac{1}{447}$ of that resulting from the potential of the homogeneous sun upon itself. Thus nearly all the energy of the solar system has resulted from the condensation of the solar mass.

I propose this evening to present the results of a determination of the potential of the sun upon itself, when the mass is heterogeneous, or made up of successive layers of a uniform density, and the density follows the laws found by our countryman, Lane, just 30 years ago, for a gaseous body in convective equilibrium. The density of each layer can be found from Lane's theory. Beginning at the center and proceeding outward, we can thence determine the average density of the included spheres when successive layers of known density are added. (The speaker here explained the theory of the integration which he had developed, and said that the mathematical discussion of the process would appear in the *Astronomische Nachrichten.*) From an astronomical point of view the problem to be solved is best treated by some process of mechanical quadrature; and accordingly I have divided the radius into 40 parts, and by successive steps obtained an integral for the potential of the heterogeneous sphere upon itself, which is almost rigorously exact. It turns out that the condensation of the heterogeneous sun

has produced more heat than the homogeneous one, in the ratio of 176,868 to 100,000. As the energy of condensation of the homogeneous sphere represents a radiation of 18 million years, the potential of this heterogeneous sphere would, on the same basis, sustain radiation almost exactly 32 million years. Thus the effect of most of the particles of Helmholtz's homogeneous sphere falling towards the center to produce the heterogeneous sphere here treated *is to prolong the life of the sun through an additional period of 14 million years.*

It has been generally held by those who have studied the theory of the sun's energy that this fiery globe can hardly continue its activity after the diameter has shrunk to one-half its present value, which would increase the average density of the sphere eight times, and make it equal to 11.2 that of water. *If this supposition be admitted, it will follow that our sun has a total longevity of thirty-six million years, of which thirty-two millions lie in the past and only four millions are available for the future life of the solar system. Thus eight-ninths of the available potential energy of the sun has been spent, and only one-ninth is available for future use.* This conclusion is based upon the assumptions : (1) That the sun's mass is gaseous and the density follows the laws found by Lane ; (2) that shrinkage will essentially cease when the globe has attained the average density of 11.2 ; (3) that the ratio of the specific heat of the solar gas under constant pressure to that of the gas under constant volume is 1.4, as in common air and most terrestrial gases, and, moreover, that the average specific heat of the sun's mass is not enormously great, so that the latent heat of cooling would become a great source of energy after shrinkage had entirely ceased. All these hypotheses are extremely probable, and the first two will hardly be questioned by any one. For since Wilson and Gray (*Phil. Trans.*, 1894) find by experiment that the effective temperature of the photosphere is about 8,000° C., it will follow that the temperature of the body of the sun is very much higher. According to Lane's theory this would make the temperature of the nucleus about a quarter of a million degrees Centigrade. The matter composing the body of the sun is much above the critical temperatures of all known substances, and thus is necessarily in a gaseous state, though in the nucleus it may be so far condensed, under the enormous pressure to which it is subjected, as to act like a solid or fluid of great viscosity. On the other hand, even though the central density be 28 times that of water, while the photosphere is rarer than the terrestrial atmosphere, it is hardly conceivable that appreciable shrinkage can go on after the average density of the globe has increased to eight times its present value. For the resistances due to molecular repulsive forces must tend to overcome gravitation pressure, and thus render further contraction impossible. If this state be not fully realized when the sun's radius has sunk to one-half its present value, it must yet be so fully attained in the greater part of the body of the sun that what further shrinkage is possible in the external layers will produce little available energy for maintaining the sun's heat.

As to the average specific heat of the sun we can only say that water has the greatest specific heat of all known terrestrial substances, and it is not probable that the average specific heat of the dense gases composing the sun can be enormously greater than that of the specific heats of the corresponding gases found upon our earth. Thus it is not likely that our sun can long maintain its radiation after shrinkage has ceased.

From this investigation it seems that the future duration of the sun's heat can hardly exceed four million years, and a corre-

sponding limit is set for plant and animal life upon our globe.

T. J. J. See.

U. S. Naval Observatory, Washington, D. C., May 12, 1899.

ON THE NEW GENUS OF LAMPREY, MACROPHTHALMIA CHILENSIS.

The preliminary account of Dr. Plate's remarkable discovery published in the *Sitzungsberichte der Gesellschaft Naturforschende Freunde*, Berlin (1897, No. 8, pp. 137–141), has, as far as I am aware, received no comment in recent literature, although there can be little doubt that this remarkable Cyclostome has revived more of the important discussions as to the position of the Cyclostomes than any publication since the time of the classic pamphlet of Professor Dohrn, '*Der Ursprung der Wirbelthiere.*' And morphologists will, I am sure, await impatiently a further discussion of the anatomy of this newly discovered type, shortly to appear in the *Fauna Chilensis* in the Supplement Volume of the *Zoologische Jahrbücher*.

As the preliminary account is not readily accessible, it may be noted that this remarkable lamprey has large and normally developed eyes. It measures but 107 mm. in length, is of a brilliant silver-white color, and its sides are literally compressed, as in the case of many of the typical bony fishes. The back region is blue-black, with light yellow, dusky flakes on the anterior half of the forehead. It is also noteworthy that the sides of the body are perfectly smooth, lacking the markings of the muscles, common in other Cyclostomes. The nasal opening is slit-like, situated anterior to the eyes, and not opening in a papilla. The gill-slits are vertically compressed. The eye is of extraordinary size, 2.5 mm. in diameter, and resembles outwardly the eyes of a Teleost, with a circular pupil, 1 mm. in diameter. The dentition is relatively simple, and is said to resemble that of Myxine.

Plate has not as yet expressed his opinion as to the significance of his morphological prize; but, judging from a single phrase in his paper, he appears to regard it as a form which has not assumed parasitic habits, and has, therefore, not been subjected to degeneration. To what degree, however, will he support Dohrn's earlier teachings, which derived the Cyclostomes from a teleost-like ancestor? In any case, this discovery will by no means simplify the difficult problem as to the relationships of the Cyclostomes in general, for it is not unnatural to assume that if one of these forms has evolved normally developed eyes probably the others also may originally have possessed them, and that the present condition of cornea, lens and retina may reasonably be interpreted as degenerate instead of primitive. On the other hand, as far as the preliminary account enables one to judge, it is also possible to assume that under favorable conditions the Hyperoarte may have become highly specialized to the degree, indeed, of acquiring a more teleost-like body form, together with more completely developed visual structures. It is to be hoped that Dr. Plate has succeeded in collecting material which will throw light upon the relations of this new type from the standpoint of metamorphosis and embryonic development.

Bashford Dean.

NOTE ON THE SPAWNING SEASON OF THE EEL.

The recent and most interesting work of the Italian naturalists Grassi, Calandruccio and Ercolani has added, in all essential regards, the needed information regarding the spawning time, as well as the metamorphosis, of the eel. I do not find, however, in my review of the literature, any definite observations with regard to either